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Ecology

Daily activity of threatened canopy mammals in a private protected natural area of tropical southeastern Mexico

Actividad diaria de mamíferos del dosel amenazados en un área natural protegida privada del sureste tropical de México

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Abstract

Private Conservation Areas (CPAs) are a complementary resource to support mammal conservation in tropical regions of the world. However, their small surface area can exert a differential influence on the species present in terms of behavior and affect their coexistence. During the 2016 rainy season, we investigated the daily activity patterns of canopy mammals in a 100 ha CPA in a rainforest. For this, 11 camera traps were placed in the trees, 15 m high. *Sciurus deppei* showed diurnal activity, *Potos flavus* around midnight, and *Caluromys derbianus* and *Coendou mexicanus* before and after midnight. *Tamandua mexicana* and *Didelphis marsupialis* were active throughout the night. Nocturnal mammals showed great overlap in their hours of activity. Overall, there were no differences in canopy mammal activity patterns in this APC compared to those reported in larger protected natural areas. The greatest number of records occurred in the tallest trees located in the best-preserved parts of the study area, suggesting the importance of APCs being forested for the conservation of canopy mammals.

Keywords: Activity overlap; Arboreal mammals

Resumen

Las áreas de conservación privadas (APC) son un recurso complementario para favorecer la conservación de los mamíferos en las regiones tropicales del mundo. Sin embargo, su reducida superficie puede ejercer una influencia diferencial sobre las especies presentes en términos de comportamiento y afectar su coexistencia. Durante la temporada de lluvias de 2016 investigamos los patrones de actividad diaria de los mamíferos del dosel en una APC de 100 ha en una selva. Para ello, se colocaron 11 cámaras trampa en los árboles, a 15 m de altura. *Sciurus deppei* presentó actividad diurna, *Potos flavus* alrededor de la medianoche y *Caluromys derbianus* y *Coendou mexicanus* antes y

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después de la medianoche. *Tamandua mexicana* y *Didelphis marsupialis* estuvieron activos durante toda la noche. Los mamíferos nocturnos mostraron gran superposición en sus horas de actividad. En general, no hubo diferencias en los patrones de actividad de los mamíferos del dosel en esta APC en comparación con los reportados en áreas naturales protegidas más grandes. El mayor número de registros ocurrió en los árboles más altos ubicados en las partes mejor conservadas del área de estudio, lo que sugiere la importancia de que las APC estén forestadas para la conservación de los mamíferos del dosel.

Palabras clave: Traslape de actividad; Mamíferos arborícolas

Introduction

In the Neotropics, the northern distribution limit of the tropical rain forest (also known as tropical evergreen forest) is found at the border between the States of Veracruz and San Luis Potosí, in Mexico (Leija-Loredo & Pavón, 2017). However, these tropical forests are disappearing at an alarming rate through conversion to subsistence agriculture, grazing pastures, and urban areas as a response to the needs of a growing human population and as a consequence of several complex socioeconomic factors as well as climate change (Altieri & Toledo, 2011; Laurance et al., 2014). From 1993 to 2002, the tropical rain forest of Mexico suffered a reduction of 24.8% in its covered area and, by 2016, its mature state covered only 0.6% of the national territory (Moreno-Sánchez et al., 2011; Santos-Hernández et al., 2021). Tropical forests present the most complex and developed vegetation canopies, hosting a prolific biodiversity that includes epiphytes (9% of the extant vascular plants), insects, birds, mammals, and microbiotas (bacterial and fungal assemblages) (Haysom et al., 2021; Nakamura et al., 2017).

Protected natural areas (PNAs), such as national parks or biosphere reserves, constitute one of the most common approaches for biodiversity conservation. However, since these areas are designed to protect large tracts of conserved habitat (Halffter, 2005), particularly in the tropics, there is an ever-decreasing amount of land available for decree as PNA. Small fragments of protected habitat, frequently under private ownership (Gallina & González-Romero, 2018; Stolton et al., 2014), may therefore complement or strengthen connectivity among large but isolated PNAs and contribute, given an appropriate spatial design, to regional maintenance of biodiversity and several ecosystem services (Holmes, 2013). However, private conservation areas (PCA) can present some disadvantages compared to larger protected natural areas, given the mostly small extension of the former. For example, in Latin America and the Caribbean region, the average size of PCA is 13.86 km^2 (n = 1,448) compared to the 1,908.2 km^2 of an average public conservation area (n = 8,373) (UNEP-WCMC, & IUCN, 2023). The disadvantages of small-sized PCA include a higher risk of impact by diseases, pests, or natural disasters, as well as a lower probability of hosting viable population sizes of those species that require extended home ranges (Hernández-Huerta, 1992; Volenec & Dobson, 2020). In addition, small PCA may differentially and detrimentally alter the behavior of some species (Wong & Candolin, 2015), and they often predominantly host common species while the rare species have been lost (Gaston et al., 2008).

A reduction in area available for the home ranges of mammals may alter their activity patterns. The daily activity pattern of mammals refers to the periods of the day during which each displays activity in order to fulfill its needs for feeding, mating, and socialization. The most common patterns are nocturnal (active during the night), diurnal (active during the day), crepuscular (activity at twilight), or cathemeral (randomly active throughout the day; Ashby, 1972). The normal activity pattern can be modified by stress factors, leading to different degrees of overlap of the activity patterns that depend on the limitation of resources (food, shelter, etc.) and/or the antagonistic interactions with sympatric species, among other factors. For example, a reduced overlap of activity patterns is often interpreted as a temporal niche partitioning that works to minimize the risk of competition (Frey et al., 2017). Thus, studies on the effect of small natural areas on the activity of the species they are supposed to conserve can be helpful to effectively manage both the protected area and the species. This is even more urgent in the case of evasive or cryptic species such as canopy mammals. The main objective of this case study was to use camera-traps to investigate the patterns of daily activity, and their degree of overlap, of arboreal mammals in a small PCA. We also assessed whether the overall activity of canopy mammals was related to the size of the trees.

Materials and methods

The study area is located in Ixhuatlán del Sureste, in the south of the State of Veracruz, Mexico, within the Ceratozamia Protection and Development Area, a

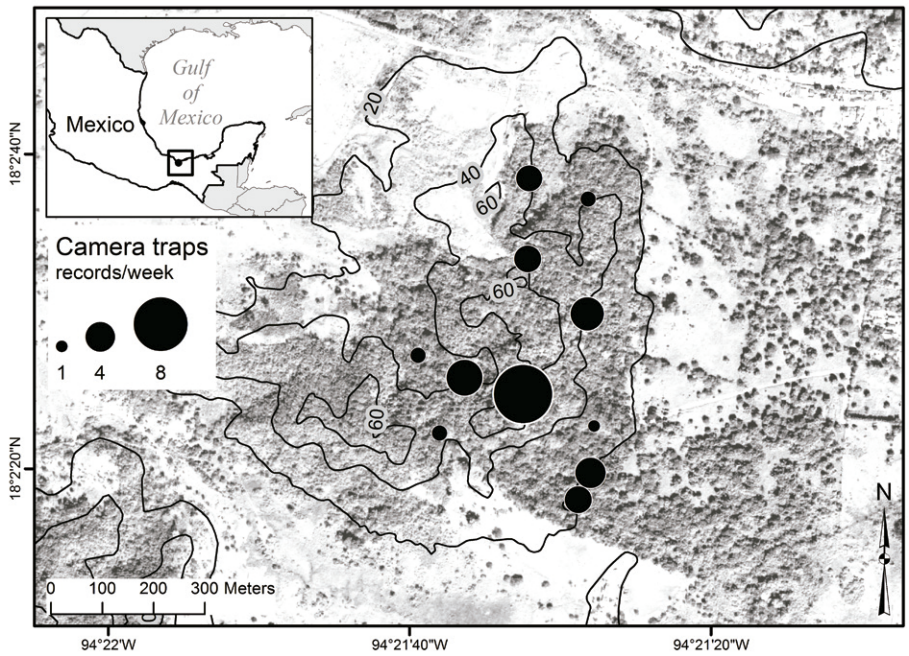

Figure 1. Study area showing the location of trees where camera traps were set within a private natural reserve in southeastern Veracruz, Mexico. The solid lines are elevational contour lines.

private conservation area (PCA) owned by the business group Braskem Idesa. The area presents an average annual rainfall of 1,800 mm and an average annual temperature of 27 °C. It has an area of 100 ha, of which 50 ha correspond to induced pasture for livestock and 50 ha to tropical forest. The elevation of the area ranges from 15 to 65 m asl (Fig. 1). The forest area consists of a number of secondary vegetation species and remnants of evergreen tropical forest, with a tree stratum of up to 25 meters in height. The most representative species are *Miconia argentea* (Sw.) D.C., *Guazuma ulmifolia* Lam., *Cupania dentata* Moc. et Sessé ex D.C., *Coccoloba barbadensis* Jacq., *Bursera simaruba* (L.) Sarg., *Enterolobium cyclocarpum* (Jacq.) Griseb., *Cecropia obtusifolia* Bertol., *Vochysia hondurensis* Sprague, and *Pithecellobium lanceolatum* (Humb. & Bonpl. ex Willd.) Benth. In the lower tree stratum, the dominant species are *Tabernaemontana alba* Mill. and *Dendropanax arboreus* (L.) Decne. & Planch. (Ortiz-Lozada et al., 2017).

Camera traps were placed on trees with a crown in contact with the canopy of other trees and a trunk diameter at breast height (DBH) greater than 50 cm. The average distance to the nearest tree furnished with a camera was 117 m. Eleven 14-megapixel camera traps were used, each with LED light and infrared sensor (Bushnell® Trophy Cam Aggressor Brown Mod. 119774). Each camera was placed on a selected tree at an average height of 15 m and directed towards a target branch with possible crossing points. The camera traps were programmed to take 3 8-megapixel photos and a 15-second video with high-definition audio. Each camera had a 32 Gb memory card to enable storage of as much data as possible. Once programmed, the cameras were left in situ for at least 3 months during the period May-September (rainy season) in 2016. However, for some cameras their memory card got saturated fairly soon due to many windy days that caused the motion of twigs and leaves, thus activating the cameras. The average time that cameras were active was 56.5 days (range 4 -129 days). No bait was used to attract the mammal species, thus avoiding a potential artificial increase in the time spent by the animal on the tree. Mammal nomenclature followed Ramírez-Pulido et al. (2005) and Voss (2011) for *Coendou* only.

The number of records in the cameras was standardized based on the actual period each was active. To describe the daily pattern of activity, the standardized frequency of records was expressed as the number of records per hour per week, rounded to the nearest integer. To test the null hypothesis of uniform activity throughout the day or night, Rayleigh tests were run for the species, using independent records only (those separated by at least 1 hr). To determine whether there was any overlap in the

Table 1

Mean time of activity of 6 canopy mammals in the private "Ceratozamia Protection and Development Area" during the 2016 rainy season (May - September) and summary of results of the Rayleigh test for uniform distribution of activity. R is the test statistic, *p* is the probability that the null hypothesis is true.

Mammal species	Number of records	Mean activity hour	R	*p*	Extinction risk**
Potos flavus	90	00:30	0.412	< 0.0001	SP
*Caluromys derbianus**	31	00:21	0.726	0.0001	Th
*Coendou mexicanus**	31	01:25	0.389	0.0082	Th
Didelphis marsupialis†	29	N/A	0.240	0.1886	
Sciurus deppei	25	08:31	0.607	0.0001	III#
Tamandua mexicana†	23	N/A	0.322	0.0914	D

** According to the Official Mexican Norm NOM-059 (Diario Oficial de la Federación, 2019): SP = special protection, Th = threatened, D = in danger of extinction. * Species presented a bimodal pattern of activity; therefore, the mean activity hour should be interpreted accordingly in these cases. † Species presented a uniform distribution of activity during the night; N/A = not applicable. # CITES appendix number: trade allowed only on presentation of the appropriate permits or certificates.

activity patterns of the arboreal mammals, we used a descriptive measure of the degree of similarity between 2 Kernel density curves, estimated by the overlap coefficient Δ (Ridout & Linkie, 2009). This measure is defined as the area in common under the 2 probability densities for the daily activity of 2 species (Schmid & Schmidt, 2006): its values range from 0, with no overlap between the activity of the 2 species, to 1, with complete activity overlap (Frey et al., 2017; Mugerwa et al., 2017). We estimated the overlap coefficient between pairs of species(which is appropriate for sample sizes smaller than 50) through the Overlap library from R (Meredith & Ridout, 2014) and its 95% confidence intervals, using bootstrap resampling with 1,000 iterations (Ridout & Linkie, 2009). During the study period, local sunrise occurred at around 07:00 and local sunset around 19:30 h. The relationship between activity (irrespective of mammal species) and tree size was investigated through a regression analysis of the values of tree diameter at breast height (DBH) —as a proxy for tree size— and the log (number of activity records). All statistical analyses were performed in R v. 3.4.3 language (R Core, 2017).

Results

With a total sampling effort of 990 camera-days, we obtained 68,287 records (51,659 photographs and 16,628 videos), of which 1,447 were considered valid. Of these records, only 233 (16%) provided sufficient elements with which to identify 9 mammal species, the most common of which are listed in Table 1. The other 3 species, the raccoon (*Procyon lotor*) and 2 rare marsupials, the Mexican mouse opossum *(Marmosa mexicana*) and the gray 4-eyed opossum (*Philander opossum*), had less than 3 records. Four of the recorded species are included under some category of extinction risk. In addition to mammals, we also recorded 26 species of birds (9 with video or photo records, 24 with acoustic records), and 2 species of reptiles (*Iguana iguana* and *Anolis* sp.).

The activity patterns of the mammal species with sufficient records are presented in Figure 2. Except for *Sciurus deppei* (Deppe's squirrel), these species are all nocturnal. The species that showed concentrated activity at certain times of the night were *Potos flavus* (kinkajou), at around 00:00 hours; *Caluromys derbianus* (Derby's woolly opossum), with most activity presented before and after midnight (21:00 to 23:00 h and 1:30 – 3:30 h); and *Coendou mexicanus* (Mexican tree porcupine), with greatest activity recorded after midnight (01:00 to 04:00 h). The species that presented uniformly spread activity throughout the night were *Tamandua mexicana* (northern tamandua) and *Didelphis marsupialis* (common opossum; Table 1). The Deppe's squirrel was mainly active in the early hours of the morning. In general, for the 5 nocturnal species, there was broad overlap of activity hours, with overlap coefficients ranging from 0.64 to 0.80 (Fig. 3). The number of records was positively associated with the tree DBH value (Fig. 4).

Discussion

This study presents a case in a small private conservation area (PCA) in which the patterns of activity of medium-sized canopy mammals are generally similar to those

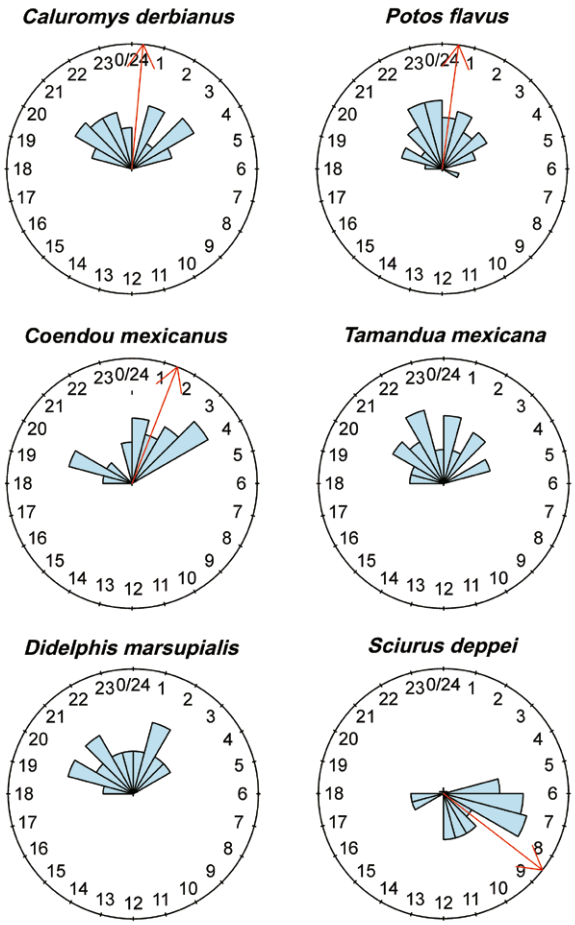

Figure 2. Rose diagrams of the daily activity patterns of the canopy mammals with most records in camera traps set in a private natural area in Veracruz, Mexico. Shaded bars are the square root of the relative frequency of records in one-hour intervals. Arrows denote the mean activity hour (not shown for species that presented a uniform distribution of activity throughout the night).

found in 2 much larger protected areas of comparable climate and vegetation: in a recent study of canopy mammals conducted in a semideciduous tropical forest of the 1,000 ha PCA Santa Gertrudis Ecological Reserve in central Veracruz, Mexico, Astiazarán-Azcárraga et al. (2020) report that the squirrel *S. aureogaster* was the only diurnal mammal to present an activity peak in the morning, while the kinkajou was mainly active around midnight and the common opossum (*Didelphis marsupialis*) presented continuous activity throughout the night. In contrast to those findings, in our study site, the northern tamandua (*Tamandua mexicana*) presented activity throughout the night rather than just around midnight. This difference could be explained by the reported ability of this species to adapt to different or unfavorable situations (Montgomery, 1985). In La Encrucijada Biosphere Reserve, located in Chiapas, Mexico, a 144,868 ha PNA dominated by mangrove and tropical evergreen forests, Hernández-Hernández et al. (2018) report 23:17 as the mean activity hour for *D. marsupialis* and 00:24 for *Philander opossum*, with an activity peak between 20:00 - 22:00 h. Similarly, in our studied PCA, the common opossum showed a mean activity hour near midnight, but the only 2 records of *P. opossum* occurred at 01:00 and 05:00. The diurnal howler monkey did not appear in our video or audio recordings, despite the fact that it is present in the studied reserve (Ortiz-Lozada et al., 2017). This is probably due to its preference for branches higher in the trees than those used to place the cameras.

The kinkajou was the mammal with most activity records concentrated around midnight. Based on characteristic markings, we estimated that at least 3 different individuals of this species were recorded throughout the study. The activity records of the Derby's woolly opossum and the Mexican tree porcupine suggest a bimodal pattern, with marked activity before and after midnight, the time of greatest activity of the kinkajou. Further studies with the capacity to collect sufficient data throughout the year would clarify whether these species are actively avoiding encounters with this procyonid. Only 2 species, the common opossum and the northern tamandua, presented activity that was evenly distributed throughout the night. The observed activity pattern (early in the morning and before dark) of the squirrel *Sciurus deppei* confirms the observations reported previously (Estrada & Coates-Estrada, 1985; Goodwin, 1954). However, to the best of our knowledge, ours is the first detailed record of activity for this elusive arboreal rodent restricted to Central America.

We found a wide overlap of activity among the nocturnal canopy mammals that coincides with previous studies (Astiazarán Azcarraga et al., 2020; Mella-Mendez et al., 2019); however, because our results summarize the activity pattern of the entire protected area, we cannot dismiss the possibility that some species avoid interaction with others on particular nights, simply by foraging on different trees or feeding from different resources inside or outside the protected area (Oliveira-Santos et al., 2008). Furthermore, because of the small area of the PCA, there is a possible ongoing species spatial aggregation effect, and some of the video recordings could feature the same individual, notwithstanding the one-hour separation rule for considering independent records. At any rate, the confirmation of the presence of these threatened mammals

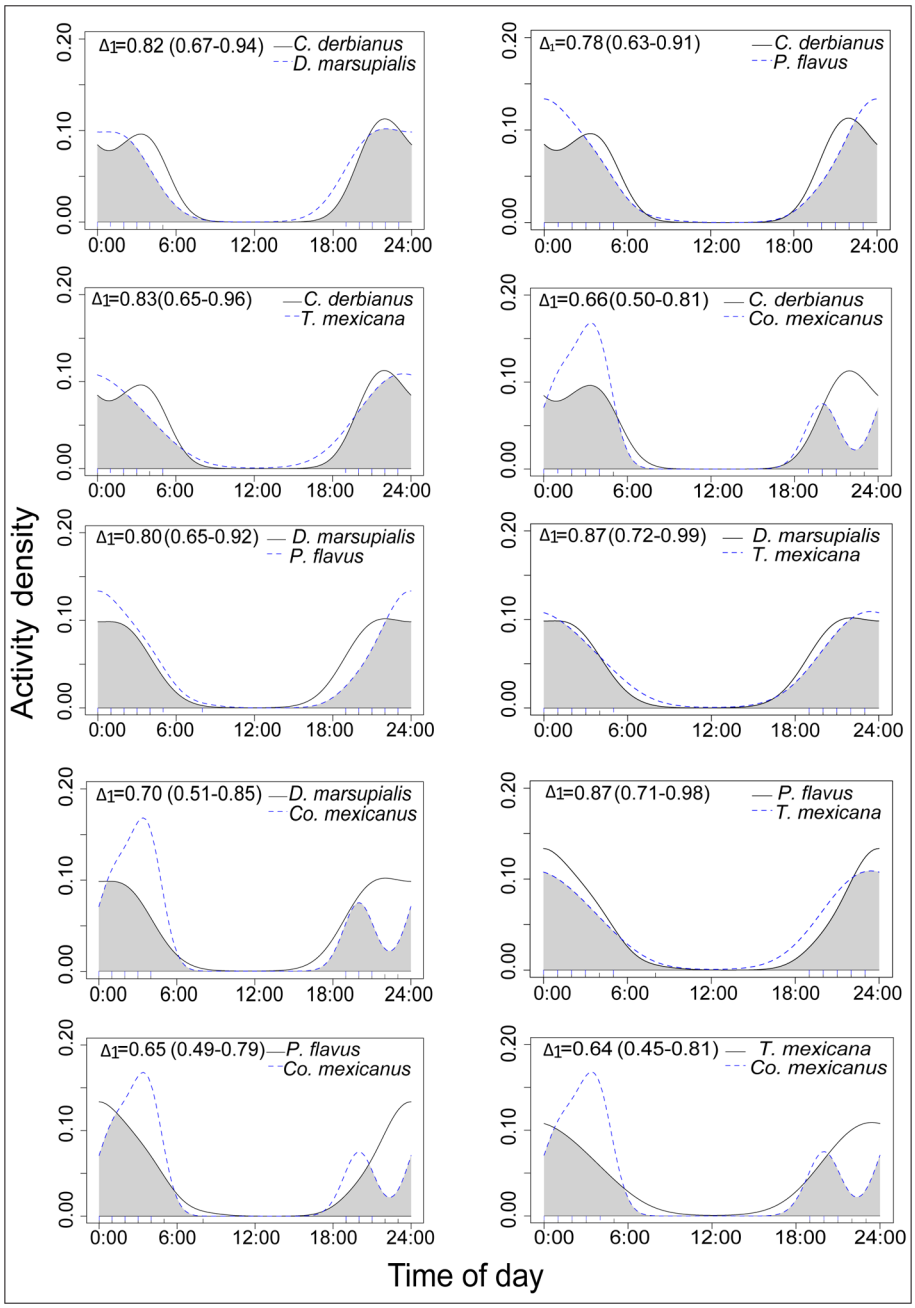

Figure 3. Overlap of the daily activity patterns of the nocturnal canopy mammals with most video records taken in a private natural area in Veracruz, Mexico. Δ1, with its 95% confidence intervals in parentheses, is the overlap coefficient and is represented by the gray area on each graph.

in a relatively small PCA still supports the utility of private areas for biodiversity conservation.

We obtained the largest number of activity records from cameras placed on the trees with greater DBH, which were usually the tallest individuals and were located at the most elevated and undisturbed points within the protected area. This strongly suggests that, at least for small PCA, large trees are essential elements in the landscape for canopy mammals to find roosting sites, concealment, and/or food within them.

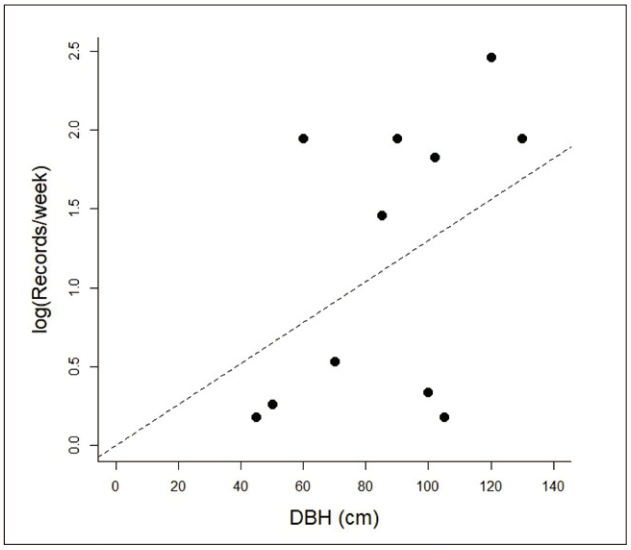

Figure 4. Linear trend between the activity records of canopy mammals and diameter at breast height (DBH). Line fitted with: log(records) = 0.0138 (DBH); $R^2 = 0.72$, $p = 0.0003$.

Despite the relatively small size of the forested area (less than 50 ha) of the PCA, we recorded the activity of canopy species, which are elusive mammals of importance given their current status as threatened or in danger of local extinction, as well as the ecosystem services they provide. Some of these species are important pollinators (*Marmosa mexicana*) or seed dispersers (*Potos flavus*, *Coendou mexicanus*, and *Caluromys derbianus*), that contribute to forest regeneration and functioning (Charles-Dominique et al., 1981). More studies with a greater sampling effort (higher number of camera-traps and a more extended sampling period), focused on specific behavior patterns (e.g. foraging and searching for a mate) of the canopy mammals in small protected natural areas will determine the extent to which the coexistence of these threatened species is assured.

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